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RESEARCH

Cleaning methods effects on the physical properties of denture resin: an *in vivo* study

Peixi Liao[*†] **and Yuwei Fan**

Department of Restorative Sciences and Biomaterials, Henry M. Goldman School of Dental Medicine, Boston University, Boston, MA, United States

[*]**Correspondence:**
Peixi Liao,
liaopx@bu.edu

[†]**ORCID:**
Peixi Liao,
0000-0002-4279-1045

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Objectives: This study aims to assess the impact of staining by various beverages, treatment with four cleaning methods, and determine the optimal cleaning approach on the physical properties of denture base resin.

Methods: A total of 200 square specimens (20 × 20 × 2 mm) of Lucitone Fas-Por + Self-curing dental base resin were fabricated following the manufacturer's guidelines. After meticulous polishing, the specimens were divided into four groups (n = 50/group) and immersed in beverages (coffee, tea, red wine, and distilled water as control) for 14 hours. Subsequently, stained specimens were further categorized into five subgroups (n = 10/group). The treatment cycle was repeated 48 times to simulate 12 months of denture usage. Measurements of surface roughness, surface hardness, weight, thickness, and color were recorded at the baseline, 12th, 24th, 36th, and 48th cycles. The data were subjected to analysis using SPSS with the Repeated Measures General Linear Model.

Results: Significant differences in tested outcomes were observed among the groups. Changes in color, weight, thickness, and roughness were significant within groups over cycles. Notably, roughness and color exhibited significant alterations after the 48th cycle. Brushing following cleanser application proved significantly more efficient in stain removal compared to other methods. However, the subgroup employing ultrasonication after cleanser application demonstrated notably lower changes in surface roughness, weight, and thickness, coupled with higher surface hardness in coffee and tea-treated groups. Solely cleaning dentures with ultrasound showed significantly lower changes and higher surface hardness in red wine-treated groups.

Conclusions: This study recommends optimal denture base cleaning methods based on different stains. For coffee and tea stains, the application of ultrasonication after cleanser exhibits minimal impact on physical properties, offering superior efficiency in stain removal. Conversely, for red wine stains, cleaning dentures with ultrasound alone demonstrates fewer alterations in physical properties and more efficient stain removal effects.

Keywords: denture cleaning, ultrasound cleaning, denture cleanser, physical property, denture base resin

Introduction

The escalating population of elderly individuals relying on dentures underscores the imperative need to emphasize preventive measures and protective strategies against denture staining, coupled with a decreased occurrence of defects (1). Inadequate denture hygiene poses a substantial risk for both oral infections and systemic dissemination, as noted in previous research. Sumi et al. (2) highlighted that denture bases may serve as reservoirs for bacteria, contributing to the development of aspiration pneumonia, opportunistic infections, and endocarditis. The porous nature of most denture materials, particularly acrylic resins, renders them susceptible to bacterial adherence, especially when the denture surface is scratched due to improper cleaning methods (3, 4). Maintaining optimal denture cleanliness, achieved through appropriate cleaning methods, becomes pivotal for patients with compromised resistance to infections (5).

Denture hygiene can be achieved through either mechanical or chemical procedures (6, 7). The chemical approach involves using an alkaline peroxide solution with active ingredients, inducing the release of oxygen bubbles that detach biofilm from the denture surface (8). This method, while effective, also possesses antibacterial properties and aids in stain removal (9–13). Mechanical methods, such as brushing, sonic vibrators, and ultrasonic devices, offer alternatives for denture cleaning (14). Brushing, which is the most commonly employed method (15–17), has been extensively reported, although concerns about potential wear and superficial damage to denture base resin persist (18–22). Ultrasonic devices, introduced as mechanical aids for denture cleaning, utilize sound waves to induce liquid movement (vibration) and the collapse of bubbles formed during the vibration process (23, 24). While combining chemical and mechanical cleaning methods seems advantageous, its effectiveness remains untested. Despite the American Dental Association (ADA) protocol recommending denture immersion in a cleanser once a week followed by brushing, the longevity and stain resistance of dentures are often compromised within months after delivery (18). Consequently, a pertinent question arises regarding the need for an efficient denture cleaning method that minimizes defects and effectively removes stains.

This study endeavors to compare the physical properties of denture base resin after staining by beverages, evaluate the impact of four distinct cleaning methods, and identify the optimal cleaning approach.

Materials and methods

A total of 200 specimens were crafted in square dimensions (20 × 20 × 2 mm). Lucitone Fas-Por + Self-curing dental base resin (Dentsply India, USA) was manipulated, packed into a lab-made metal matrix, and polymerized as per the manufacturer's instructions in a pressure pot (Ivomat, Dentek, Inc., Buffalo, USA). The excess polymerized resin was trimmed using a tungsten carbide drill (Buffalo Dental, NY, USA) employing a low-speed micromotor (Henry Schein Inc., UK). Subsequently, both flat sides of each specimen underwent polishing in the horizontal lathe spindle (AutoMet 250, Buehler, Lake Bluff, IL, USA) using 70, 45, and 15 μm diamond grinding discs. One of the flat faces of each specimen was polished with a polishing cloth and 1 μm Buehler supreme polycrystalline diamond suspension at a low speed of 200 rpm in the horizontal lathe spindle. Post-polishing, the final thicknesses of the specimens were verified using a CD-6 CSX-B digital caliper (Mitutoyo, Tokyo, Japan). The samples were marked with three carvings using a diamond drill on the lateral side. Following the markings, the specimens were stored in distilled water at 37 °C for 50 ± 2 h to eliminate residual monomer (25).

The denture cleanser subjected to testing was Polident Overnight denture cleanser (Gaxo Smith Kline Consumer Healthcare, L.P. Moon Township, PA, USA), containing principal ingredients such as sodium bicarbonate, citric acid, potassium monopersulfate, sodium carbonate, sodium percarbonate, TAED, sodium benzoate, PEG-180, sodium lauryl sulfoacetate, Aroma, VP/VA copolymer, Blue 1 aluminum lake, and Blue 2. The staining solutions utilized in this study comprised filtered coffee (100% Colombian coffee, Kirkland, Seattle, WA, USA), red wine (Central Valley Frontera Chile, Vina Conchay Toro, SA, Chile), and tea (Lipton, Unilever, Englewood Cliffs, NJ, USA), with all solutions prepared following the manufacturers' instructions. The coffee solution was created by dissolving 50 g of coffee in 500 mL of boiled water, stirring for 10 minutes, and filtering. The tea solution was prepared by immersing five teabags (10 g) in 500 mL of boiled water, stirring for 10 minutes, and filtering (26).

Immersion and cleaning procedures

The denture samples were randomly assigned to 20 groups, each with a sample size of 10 (n = 10). The primary groups were as follows: Cleanser + Brush (Group A), involving immersion in denture cleanser and brushing with distilled water; Cleanser + Ultrasound (Group B), consisting of immersion in denture cleanser and cleaning in an ultrasonic cleaner; Brush Only (Group C), entailing immersion in distilled water and brushing with distilled water; Ultrasound Only (Group D), involving immersion in distilled water and cleaning in an ultrasonic cleaner; and Control (Group E), with immersion in distilled water. Within each main group, the specimens were further divided into subgroups (n = 10) as follows: control (Subgroup I), immersion in distilled water; coffee (Subgroup II), immersion in coffee; tea (Subgroup III), immersion in tea; red wine (Subgroup IV), immersion in red wine after staining. The specimens were thus distributed across a total of 20 groups, as detailed in **Table 1**.

For the brushing test, a custom-made toothbrush machine was utilized, allowing simultaneous brushing of four sets of specimens at a frequency of 70 rpm. The brush covered a course of 3 cm, and the load was standardized at 200 gf, following ISO/DTS 145692 guidelines. The toothbrushes used in the study were Oral-B Indicator soft regular 40, with rounded ends, uniform length, flexibility, and 38 tufts (40 sticks per tuft) of smooth bristles, each with a diameter of 0.25 mm and a height of 10 mm. The specimens underwent evaluation through tests measuring

TABLE 1 | Groups and treatment timeline for each cycle.

Group	Treatment for each cycle		
A. Toothbrush	Beverage[a] 14h = = >	Distilled water 8h = = >	Brush 210 cycles
B. Ultrasound			Ultrasound 15 minutes
C. Cleanser + Toothbrush		Cleanser 8h = = >	Brush 210 cycles
D. Cleanser + Ultrasound			Ultrasound 15 minutes
E. Control		Distilled water 8.25 hours	

a. Beverage = Coffee, Tea, Red wine, or Distilled water.

weight, thickness, surface roughness, surface hardness, and color. Baseline data for the specimens were recorded before immersion.

During the experiment, the specimens were immersed in staining solutions or distilled water (control group) for 14 hours to simulate weekly exposure (2 h per day for 7 days) to beverages. After staining, the specimens were rinsed in tap water for 10 seconds and air-dried. Cleaning procedures were then applied based on the assigned groups: Cleanser + Brush (Group A), involving immersion in denture cleanser for 8 hours and brushing with distilled water in a brushing machine for 3 minutes (70 cycles/min for 210 cycles); Cleanser + Ultrasound (Group B), with 8 hours of immersion in denture cleanser and 15 minutes of cleaning in an ultrasonic cleaner (Quantrex 140, L&R, New Jersey, USA); Brush Only (Group C), including 8 hours of immersion in distilled water and 3 minutes of brushing with distilled water; Ultrasound Only (Group D), with 8 hours of immersion in distilled water and 15 minutes of cleaning in an ultrasonic cleaner; Control (Group E), involving 8 hours of immersion in distilled water (overnight). The specimens were then rinsed and air-dried, and subsequent tests were conducted. This weekly procedure was repeated, totaling 48 cycles to simulate 12 months of denture usage. All tests were repeated at baseline, and at the 12th, 24th, 36th, and 48th cycles.

Test series

The surface roughness (Ra) of the test samples was assessed utilizing a profilometer (SJ-201P, Mitutoyo Corp., Kawasaki, Japan) with a 0.4-gf load. A stylus featuring a 5 μm tip radius traversed the surface, recording data at a resolution of 0.01 μm. The specimens were affixed to the profilometer measuring table using a double-sided tape. Each sample underwent three readings over a 4.0 mm length, with a cutoff value of 0.8 mm, at a speed of 0.1 mm/s in regions corresponding to specimen marks. The roughness for each sample was determined as the arithmetic mean of three measurements (μm). The alteration in surface roughness (ΔRa) was computed as the difference between post-immersion and baseline values. Surface roughness was standardized for all resins before immersion, with standardization within each group. The Ra value represented the arithmetic average of all profile samples across the mean sample length. A single operator conducted all measurements.

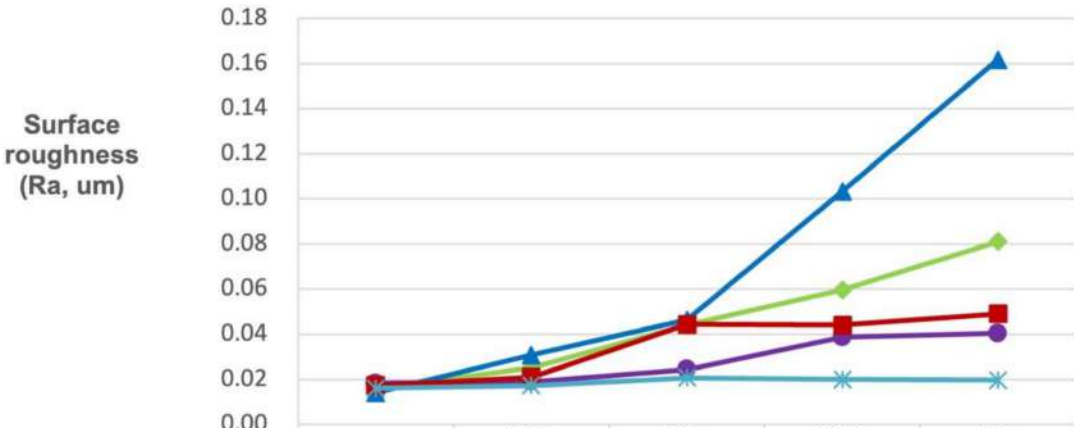
The mass of each specimen was measured using an electronic balance (AB204-SRS, Mettler Toledo, Switzerland) before and after brushing or ultrasonic cleaning. Mass loss was calculated based on the initial mass and differences after brushing or ultrasonic cleaning, with the balance offering a resolution of 0.0001 g.

Specimen thickness was measured with a CD-6 CSX-B digital micrometer (Mitutoyo, Tokyo, Japan) before and after brushing or ultrasonic cleaning. Thickness loss was determined by the initial thickness and differences after cleaning, with the micrometer's precision being 0.005 mm.

Color and color differences for each specimen were gauged using a spectrophotometer (Color i5, X rite GretagMacbeth, Mochenwangen, Germany) against a gray background. The spectrophotometer, calibrated per manufacturer instructions, recorded values in the CIE LAB color system, encompassing L* (lightness), a* (red-green), and b* (yellow-blue) coordinates. ΔL*, Δa*, and Δb* denoted differences between baseline and post-immersion values, while total color alteration (ΔE*) was calculated as $\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$.

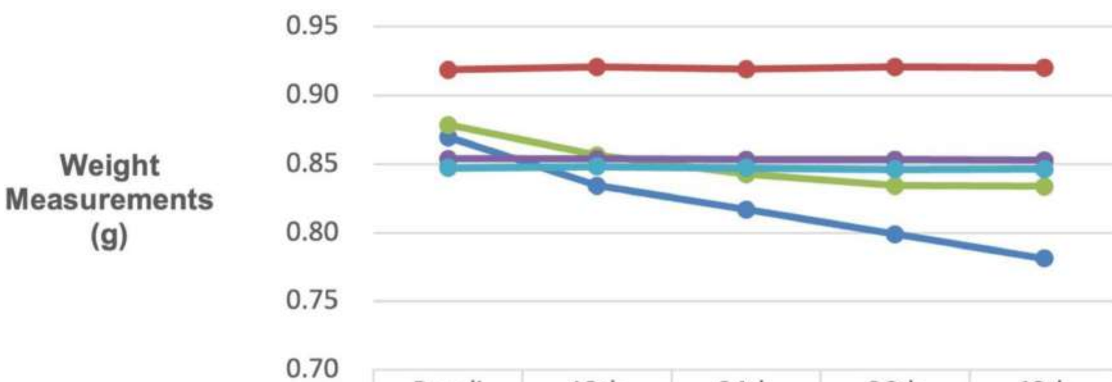
The Vickers hardness (VHN) of the test samples was determined with a Microhardness Tester (Micromet 2003, Buehler, Illinois, USA) using a 100-gf load for 30 seconds. Diagonals of the pyramid impressed on the specimen by the Vickers diamond indenter were measured under a microscope at 600×, with the VHN value being the arithmetic mean of three measurements for each sample. A single operator recorded all measurements, and the mean Vickers hardness number was then calculated for each sample. After immersion in cleaning solutions, the average value was used to represent an overall mean indicative of the materials.

Data were analyzed with SPSS on the repeated-measures general linear model. A significant level of 0.05 was used to determine the presence of significance between groups.



	Baseline	12th cycles	24th cycles	36th cycles	48th cycles
Brush	0.016	0.025	0.044	0.060	0.081
Ultrasound	0.018	0.019	0.024	0.039	0.040
Cleanser + Brush	0.014	0.031	0.046	0.103	0.162
Cleanser + Ultrasound	0.017	0.021	0.044	0.044	0.049
Control	0.016	0.017	0.021	0.020	0.020

FIGURE 1 | Surface roughness changes of different cleaning methods in water.



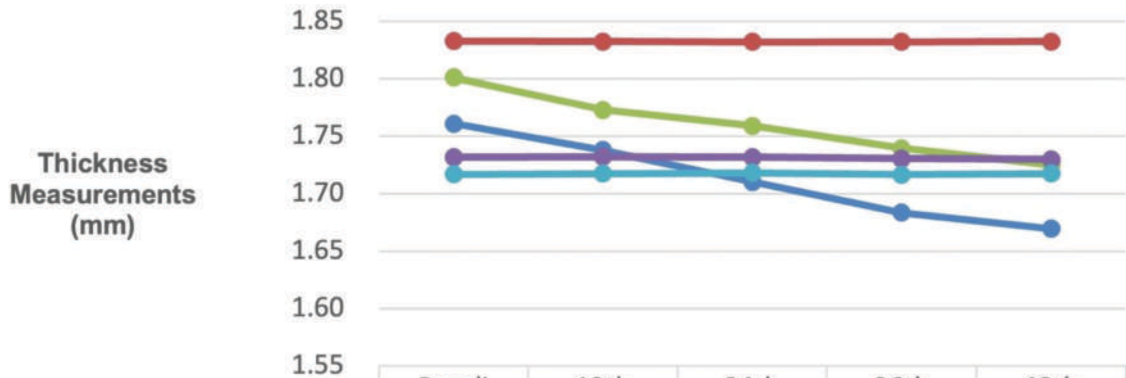
	Baseli ne	12th cycles	24th cycles	36th cycles	48th cycles
Cleanser + Brush	0.8697	0.8341	0.8169	0.7991	0.7812
Cleanser + Ultrasound	0.9186	0.9207	0.9191	0.9209	0.9203
Brush	0.8787	0.8564	0.8428	0.8344	0.8338
Ultrasound	0.8538	0.8536	0.8534	0.8532	0.8527
Control	0.8472	0.8483	0.8472	0.8461	0.8465

FIGURE 2 | Weight changes of different cleaning methods in water.

Result

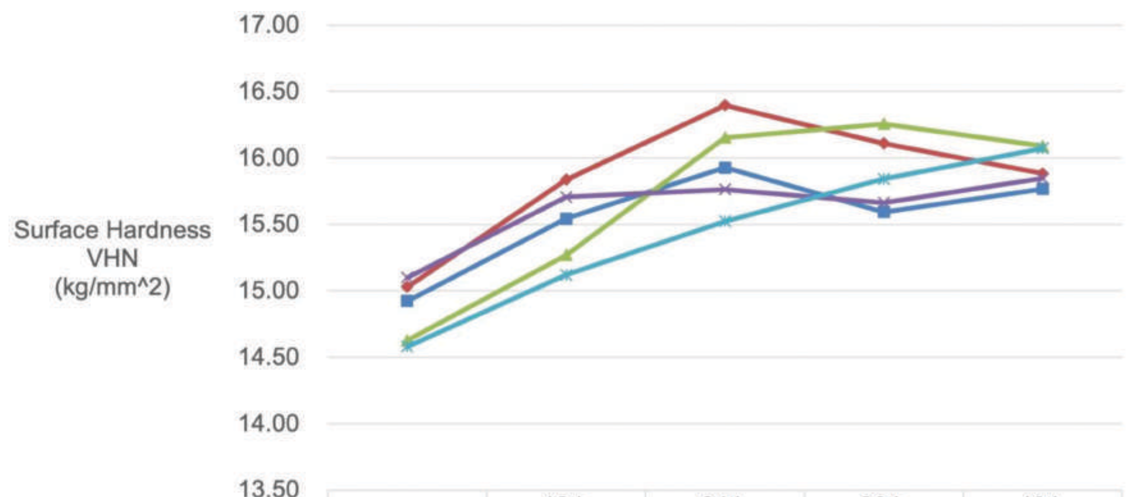
Compare the effects of cleaning methods on the physical properties of denture resin

Figure 1 shows the surface roughness changes of different cleaning methods. It is the test results in the control subgroups immersed in water. It is reversed that surface roughness increased in all treatment groups, and significantly higher values were detected at 36th and 48th cycles in brush-only groups. Meanwhile, the surface roughness significantly increased for the cleanser and brushed combined groups compared to other groups.



	Baseline	12th cycles	24th cycles	36th cycles	48th cycles
Cleanser + Brush	1.7612	1.7380	1.7105	1.6836	1.6696
Cleanser + Ultrasound	1.8329	1.8326	1.8323	1.8323	1.8325
Brush	1.8012	1.7732	1.7592	1.7398	1.7255
Ultrasound	1.7320	1.7323	1.7318	1.7306	1.7303
Control	1.7171	1.7178	1.7183	1.7169	1.7177

FIGURE 3 | Thickness changes of different cleaning methods in water.



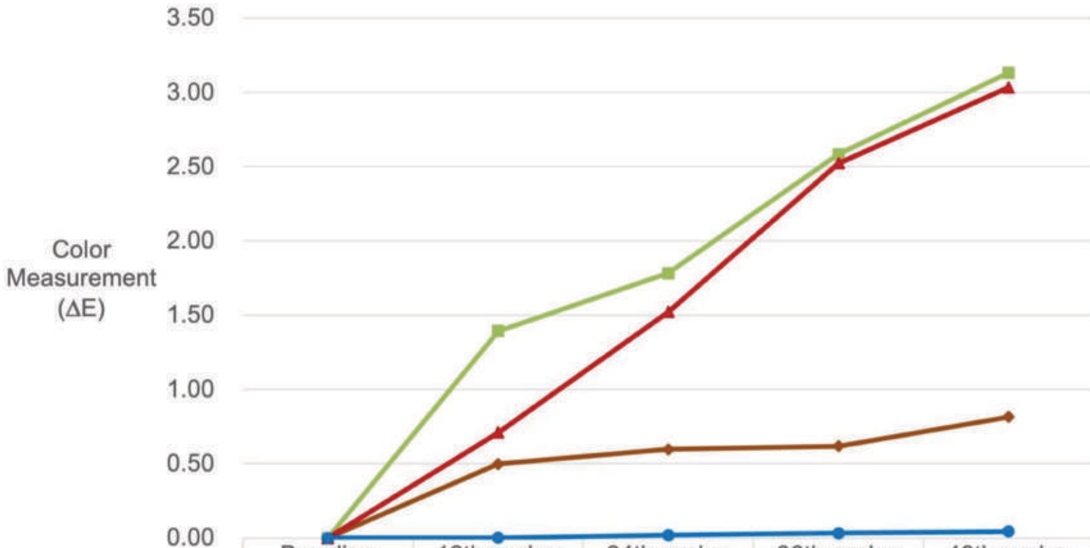
	Baseline	12th cycles	24th cycles	36th cycles	48th cycles
Cleanser + Brush	14.923	15.543	15.927	15.593	15.767
Cleanser + Ultrasound	15.030	15.837	16.397	16.110	15.883
Brush	14.627	15.270	16.153	16.257	16.090
Ultrasound	15.100	15.707	15.763	15.663	15.847
Control	14.580	15.120	15.523	15.843	16.073

FIGURE 4 | Surface hardness changes of different cleaning methods in water.

Similar changes were found in weight and thickness measurements, in which cleanser and brush combined methods caused defection on the specimens (**Figures 2** and **3**). In the surface hardness changes, all groups showed a trend of increase. However, no significant difference was detected between all the groups (**Figure 4**).

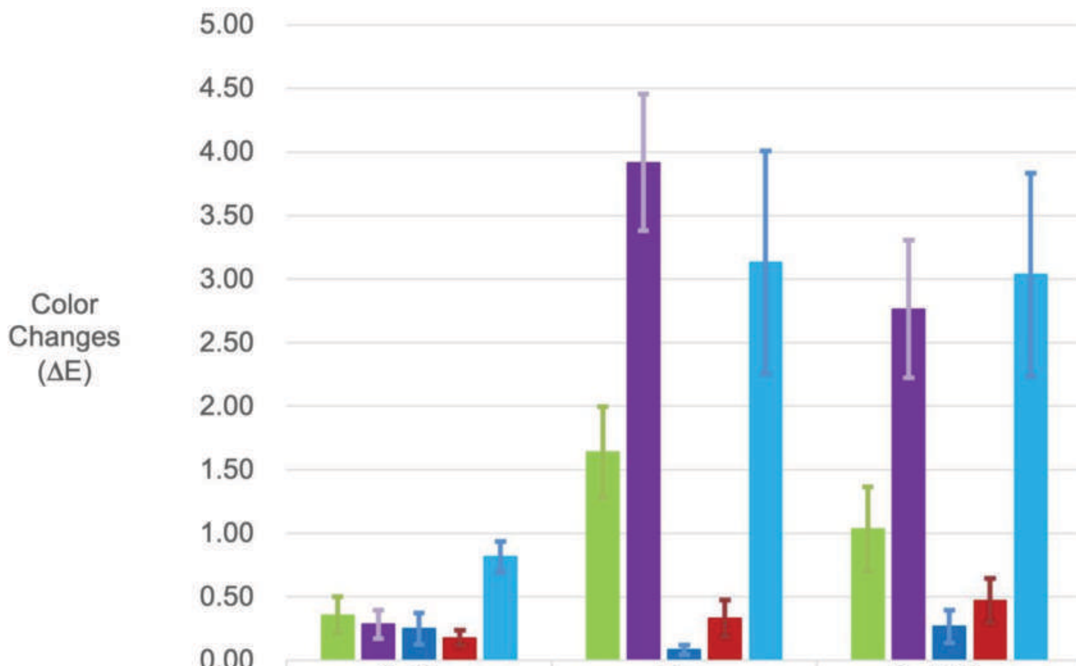
Compare staining effects on denture resin

Figure 5 shows the color changes of different staining. This result came from the test results in the control groups, in which no cleaning treatment was applied while immersed items were in the staining solution. The results



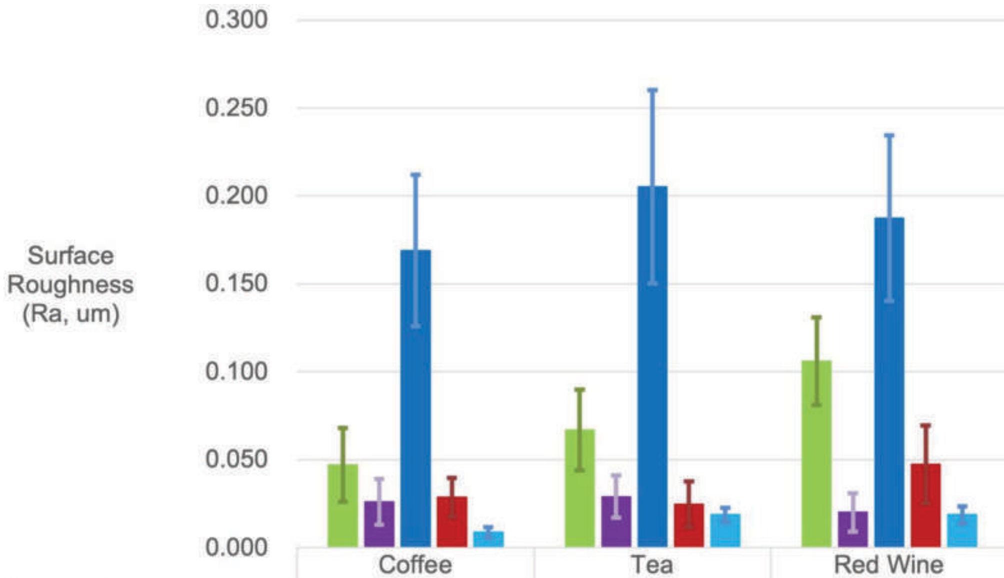
	Baseline	12th cycles	24th cycles	36th cycles	48th cycles
Coffee	0.0000	0.4983	0.5978	0.6179	0.8158
Tea	0.0000	1.3939	1.7815	2.5830	3.1325
Red wine	0.0000	0.7106	1.5214	2.5231	3.0334
Control	0.0000	0.0018	0.0198	0.0324	0.0435

FIGURE 5 | Color changes of different staining in control groups.



	Coffee	Tea	Red Wine
Brush	0.3585	1.6392	1.0341
Ultrasound	0.2862	3.9171	2.7637
Cleanser + Brush	0.2500	0.0833	0.2674
Cleanser + Ultrasound	0.1778	0.3304	0.4708
Control	0.8151	3.1325	3.0334

FIGURE 6 | Color changes of different cleaning methods in stains at 48th cycles.



	Coffee	Tea	Red Wine
Brush	0.047	0.067	0.106
Ultrasound	0.026	0.029	0.020
Cleanser + Brush	0.169	0.205	0.187
Cleanser + Ultrasound	0.029	0.025	0.047
Control	0.009	0.019	0.019

FIGURE 7 | Surface roughness changes of different cleaning methods in stains at 48th cycles.

showed water made no apparent changes, coffee made color changes, but tea and red wine made a significant change in color of the denture.

Compare staining and cleaning effects on denture resin

Different cleaning methods have different abilities to remove stains, and they have different abilities to create defection of the denture at the same time.

Figure 6 shows the results of surface roughness changes of different cleaning methods at the end of treatments, which is 12 months of usage of the denture following different cleaning protocols. It shows that all stains, cleanser, and brush combined cleaning, which ADA recommends, invariably cause the maximum damage. Meanwhile, ultrasound and cleanser ultrasound cleaning methods caused the minimum defects. **Figure 7** shows the color changes of different cleaning methods at the end of our treatments. For all stains, cleanser ultrasound and cleanser brush cleaning methods have the best discoloration ability. Unfortunately, according to this result, different cleaning methods' discoloration and defection abilities are not matched as expected. In this study, the Repeated Measures General Linear Regression Statistical Model was used to measure the weights of different effects (**Table 2**). **Table 3** lists all the test runs on the specimens and the desirability and priority put into the statistical model.

After considering the priority and desirability of these statistical models, the result was obtained to choose the optimal cleaning methods for denture resin from different stains. 1. In coffee stains, the cleanser and ultrasonication combined method showed the best for denture resin in most tests, while cleanser and brush clean combined techniques are more efficient in removing the stain. 2. In tea stains, the same patterns were found as the coffee stains. 3. In red wine stains, ultrasound cleaning only showed the best denture resin in most tests, while the cleanser and brush clean combined method was more efficient in removing the stain.

Discussion

The outcomes of this study substantiate the rejection of the null hypothesis, asserting that the amalgamation of ultrasonic treatment with denture cleanser elicits optimal cleaning efficacy. The current investigation aligns harmoniously with the findings of Palenik et al. (27) where ultrasonic devices paired with tap water showcased a cleaning action predominantly propelled by ultrasonic cavitation, rather than the inherent chemical composition. Undoubtedly, this underscores the significant capacity of ultrasonic devices to substantially curtail cleaning time, as reported by Palenik et al. (reduction by 1/420 to 2/3) (28, 29). However, it is imperative to acknowledge the nuanced impact on surface roughness, as elucidated by Palenik et al. and Otake and Yoshida (30).

TABLE 2 | Summary of multiple comparison tests (*P*-values between each cleaning method) in surface roughness.

Comparisons	Main Effect	Time Effect	Interaction	Difference Detection*
Cleanser + Brush vs. Brush	0.005	<0.001	0.004	36th cycles
Cleanser + Ultrasound vs. Ultrasound	0.980	0.002	0.710	N/A
Cleanser + Brush vs. Cleanser + Ultrasound	<0.001	<0.001	<0.001	24th cycles
Brush vs. Ultrasound	<0.001	<0.001	<0.001	12th cycles
Cleanser + Brush vs. Control	<0.001	<0.001	<0.001	12th cycles
Cleanser + Ultrasound vs. Control	0.169	0.012	0.534	N/A
Brush vs. Control	<0.001	<0.001	<0.001	12th cycles
Ultrasound vs. Control	0.141	0.004	0.684	N/A

*When P 0.05 detected in the multiple comparison tests of between-subjects effects.

TABLE 3 | Statistical model used in data analysis (Repeated measures general linear regression).

Tests	Desirability	Priority
Surface Roughness	Minimum	1st
Color Measurements	Minimum	2nd
Surface Hardness VHN	Maximum	3rd
Weight Measurements	Minimum	4th
Thickness Measurements	Minimum	5th

The assessment of denture color stability involved an examination of the efficacy of various cleaning methods. The susceptibility of dentures to staining was found to be dependent on the staining solution used in this research. Statistical analysis uncovered noteworthy differences in the staining capabilities of various solutions. Notably, red wine and tea exhibited a higher degree of discoloration compared to coffee. The discernible color variations induced by red wine and tea were evident to the human eye ($\Delta E^* > 3.3$), aligning with findings from prior studies (31–34). Previous research has suggested that the alcohol content in red wine, as tested in this study, may contribute to surface roughening, thereby facilitating staining by softening the resin matrix. Consistent with our study, the literature indicates that tea tends to exert a more pronounced discoloration effect on polymeric dental materials than coffee (35, 36).

In response to the potential deleterious effects on denture base resin, this study advocates a strategic approach—employing ultrasonic treatment subsequent to the application of denture cleanser. This sequential protocol aims to mitigate the negative repercussions on denture base resin, as expounded upon in this investigation.

Delving into a meticulous critique of the experiments, this discussion underscores the critical significance of the concurrent utilization of ultrasonic treatment and denture cleanser. A more detailed examination of ultrasonic cavitation as a pivotal cleaning mechanism and its discernible effects on surface roughness now provides a nuanced understanding of the experimental nuances.

The limitations of the study are elucidated in greater detail, encompassing a comprehensive exploration of potential drawbacks. Emphasis is placed on the potential negative influence on denture base resin and the discernible increase in surface roughness, offering a holistic comprehension of the study's constraints.

The discussion dedicates a considerable segment to delineate potential avenues for future research, emphasizing the necessity for more nuanced investigations. Specifically, it underscores the need for further exploration into diverse chemical compositions within the ultrasonic device, leveraging a meticulously designed clinical trial framework.

Conclusion

Within the scope of this study, the optimal selections of denture base cleaning methods for different stains are suggested. For coffee and tea stains, ultrasonication after cleanser application causes a more negligible effect on physical properties and better efficiency for stain removal than other cleaning methods. For red wine stains, cleaning dentures with ultrasound only causes less impact on physical properties and more efficient stain removal.

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